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ATTORNEY'S DOCKET NO.

970054.413USPC

U.S. APPLICATION NO. (If known, see 37 CFR 1.5)

Unknown

10/088011

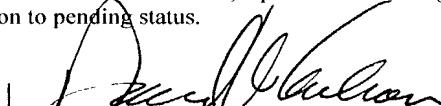
**TRANSMITTAL LETTER TO THE UNITED STATES  
DESIGNATED/ELECTED OFFICE (DO/EO/US)  
CONCERNING A FILING UNDER 35 U.S.C. 371**INTERNATIONAL APPLICATION NO. INTERNATIONAL FILING DATE  
**PCT/EP00/08745 07 September 2000 (07.09.00)**PRIORITY DATE CLAIMED  
**13 September 1999 (13.09.99)****TITLE OF INVENTION****METHOD OF REACTIVE POWER REGULATION AND APPARATUS FOR PRODUCING ELECTRICAL ENERGY IN AN  
ELECTRICAL NETWORK****APPLICANT(S) FOR DO/EO/US****WOBBEN, Aloys**

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1.  This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2.  This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3.  This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (21) indicated below.
4.  The US has been elected by the expiration of 19 months from the priority date (Article 31).
5.  A copy of the International Application as filed (35 U.S.C. 371(c)(2)).
  - a.  is attached hereto (required only if not communicated by the International Bureau).
  - b.  has been communicated by the International Bureau.
  - c.  is not required, as the application was filed in the United States Receiving Office (RO/US).
6.  An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
  - a.  is attached hereto
  - b.  has been previously submitted under 35 U.S.C. 154(d)(4).
7.  Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3)).
  - a.  are attached hereto (required only if not communicated by the International Bureau).
  - b.  have been communicated by the International Bureau.
  - c.  have not been made; however, the time limit for making such amendments has NOT expired.
  - d.  have not been made and will not be made.
8.  A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9.  An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10.  A English language translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

**Items 11 to 20 below concern document(s) or information included:**

11.  An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12.  An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13.  A FIRST preliminary amendment.
14.  A SECOND or SUBSEQUENT preliminary amendment.
15.  A substitute specification.
16.  A change of power of attorney and/or address letter.
17.  A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821 – 1.825.
18.  A second copy of the published international application under 35 U.S.C. 154(d)(4)
19.  A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
20.  Other items of information:

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                       |                                                                                                                                                                                     |            |        |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|--------|
| U.S. APPLICATION NO (If known, see 37 CFR 1.5)<br><b>Unknown 10/088011</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | INTERNATIONAL APPLICATION NO<br><b>PCT/EP00/08745</b> | ATTORNEY'S DOCKET NUMBER<br><b>970054.413USPC</b>                                                                                                                                   |            |        |
| 21. <input checked="" type="checkbox"/> The following fees are submitted:<br><b>Basic National Fee (37 CFR 1.492(a)(1)-(5)):</b><br><br>Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO ..... \$1040.00<br><br>International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO ..... \$890.00<br><br>International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO ..... \$740.00<br><br>International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4)..... \$710.00<br><br>International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4) ..... \$100.00 |                                                       | CALCULATIONS<br>PTO USE ONLY                                                                                                                                                        |            |        |
| <b>ENTER APPROPRIATE BASIC FEE AMOUNT =</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                       | \$890.00                                                                                                                                                                            |            |        |
| Surcharge of \$130.00 for furnishing the oath or declaration later than <input type="checkbox"/> 20 <input checked="" type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492(e)).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                       | \$130.00                                                                                                                                                                            |            |        |
| Claims                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Number Filed                                          | Number Extra                                                                                                                                                                        | Rate       |        |
| Total Claims                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 17 - 20 =                                             | 0                                                                                                                                                                                   | x \$ 18.00 | \$0.00 |
| Independent Claims                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | 2 - 3 =                                               | 0                                                                                                                                                                                   | x \$ 84.00 | \$0.00 |
| Multiple dependent claim(s) (if applicable)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                       |                                                                                                                                                                                     | + \$280.00 | \$0.00 |
| <b>TOTAL OF ABOVE CALCULATIONS =</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                       | \$1,020.00                                                                                                                                                                          |            |        |
| <input type="checkbox"/> Applicant claims small entity status. See 37 CFR 1.27. The fees indicated above are reduced by 1/2.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                       | \$0.00                                                                                                                                                                              |            |        |
| <b>SUBTOTAL =</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                       | \$1,020.00                                                                                                                                                                          |            |        |
| Processing fee of \$130.00 for furnishing the English translation later than <input type="checkbox"/> 20 <input type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492(f)).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                       | \$0.00                                                                                                                                                                              |            |        |
| <b>TOTAL NATIONAL FEE =</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                       | \$1,020.00                                                                                                                                                                          |            |        |
| Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). \$40.00 per property                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                       | \$0.00                                                                                                                                                                              |            |        |
| <b>TOTAL FEES ENCLOSED =</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                       | <b>\$1,020.00</b>                                                                                                                                                                   |            |        |
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| <p>a. <input checked="" type="checkbox"/> A check in the amount of <u>\$1,020.00</u> cover the above fees is enclosed.</p> <p>b. <input type="checkbox"/> Please charge my Deposit Account No. in the amount of <u>_</u> to cover the above fees. A duplicate copy of this sheet is enclosed.</p> <p>c. <input checked="" type="checkbox"/> The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. <b>19-1090</b>. A duplicate copy of this sheet is enclosed.</p> <p>d. <input type="checkbox"/> Fees are to be charged to a credit card. WARNING: Information on this form may become public. Credit card information should not be included on this form. Provide credit card information and authorization on PTO-2038.</p>                                                                                                                                                                                          |                                                       |                                                                                                                                                                                     |            |        |
| NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                       |                                                                                                                                                                                     |            |        |
| SEND ALL CORRESPONDENCE TO:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                       | <br><b>SIGNATURE</b><br><b>David V. Carlson</b><br>NAME<br><b>31,153</b><br>REGISTRATION NUMBER |            |        |
| David V. Carlson, Esq.<br>Seed Intellectual Property Law Group PLLC<br>701 5 <sup>th</sup> Avenue, Suite 6300<br>Seattle, WA 98104-7092<br>United States of America<br>(206) 622-4900                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                       |                                                                                                                                                                                     |            |        |

PATENT COOPERATION TREATY

Int'l Application No. : PCT/EP00/08745  
Int'l Filing Date : 07 September 2000  
U.S. Application No. : Not yet known  
Inventors : WOBBEN, Aloys  
Title : METHOD OF REACTIVE POWER REGULATION AND APPARATUS FOR PRODUCING ELECTRICAL ENERGY IN AN ELECTRICAL NETWORK  
Docket No. : 970054.413USPC  
Date : 13 March 2002

Box PCT  
Assistant Commissioner for Patents  
Washington, DC 20231-0001

PRELIMINARY AMENDMENT

Sir:

Please enter a Preliminary Amendment by replacing the application and claims presently on file as identified above with the enclosed substitute specification and claims prior to examination on the merits.

Respectfully submitted,

Seed Intellectual Property Law Group PLLC

  
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METHOD OF REACTIVE POWER REGULATION AND APPARATUS FOR  
PRODUCING ELECTRICAL ENERGY IN AN ELECTRICAL NETWORK

TECHNICAL FIELD

The invention concerns a method of reactive power regulation in an electrical network, in which electrical power is produced by an electrical generator preferably driven by the rotor of a wind power installation and suitably modulated by means of a compensation device between the generator and the network for the compensation of reactive power. The invention further concerns an apparatus for producing electrical energy in an electrical network, comprising an electrical generator preferably driven by the rotor of a wind power installation and a compensation device between the generator and the network for the compensation of reactive power.

BACKGROUND OF THE INVENTION

Many consumers connected to the electrical network require inductive reactive power. Compensation of such an inductive reactive power component is effected by using capacitors which are also referred to as phase-shifting capacitors whose capacitive reactance is approximately as high as the inductive reactance. Complete compensation of the inductive reactive power by means of phase-shifting capacitors is however not possible in practice precisely when high power fluctuations are involved. A further disadvantage is that the phase-shifting capacitors required, which are frequently combined together to form what is referred to as capacitor batteries and which moreover take up a great deal of space have a negative effect on the stability of the electrical network.

SUMMARY OF THE INVENTION

The object of the present invention is to compensate for the reactive power in an electrical network in a simple fashion.

In a method and an apparatus of the kind set forth in the opening part of this specification, that object is attained in that the compensation device is so regulated that the electrical power delivered to the consumer has a reactive power component which is adapted in respect of its phase, amplitude and/or frequency to  
5 the consumer in such a way as to compensate for the reactive power in the consumer.

In accordance with the invention, by means of the compensation device, a reactive power is 'produced', which is in a position to compensate for the reactive power in the consumer. For example, by means of the compensation  
10 device according to the invention, it is possible to produce a capacitive reactive power component which is adapted to the inductive reactive power component required by the consumer, in such a way that it substantially completely compensates for the inductive reactive power component in the consumer. The advantage of the invention is thus essentially that there is provided a regulating  
15 system which rapidly reacts in particular to frequently occurring high power fluctuations, so that complete reactive power compensation is substantially maintained. Accordingly, inductive or capacitive reactive power can be fed selectively into the electrical network, which in accordance with the invention is implemented by regulation of the compensation device.

20 In this respect, by means of the regulation in accordance with the invention, it is preferably also possible for the electrical power produced to be of a frequency which corresponds to the frequency of the consumer or also represents a multiple of the consumer frequency. In the former case accordingly reactive power can be supplied at the frequency of the consumer or the network frequency  
25 of the electrical network. In the latter case for example as desired harmonic reactive power can be fed into the electrical network. For example the fifth harmonic can be fed into the network, at a frequency of 250 Hz, as a capacitive harmonic. That then compensates for the harmonic reactive power of electrical

consumers which are connected to the electrical network such as for example televisions, energy-saving lamps and so forth.

Desirably the compensation device has an inverter with which phase, amplitude and/or frequency of the voltage and/or current characteristics can be

- 5 particularly easily adjusted or regulated in order to produce a reactive power component which is suitable for appropriately compensating for the reactive power in the consumer.

Preferably the compensation device has a measuring device for detecting the voltage and/or current variations in the electrical network, preferably

- 10 at the feed-in point. In a development of the embodiment in which the compensation device includes an inverter the compensation device controls the inverter in dependence on the measurement results of the measuring device.

The voltage produced by the electrical generator is preferably regulated substantially to a predetermined reference value with suitable adaptation

- 15 of the reactive power component in the electrical power delivered to the consumer. In that situation adaptation of the reactive power component can take place by suitable control of the power factor ( $\cos \varphi$ ) or the phase of the current produced by the electrical generator. If the electrical generator is connected to an electrical network by way of a line and/or a transformer then the voltage produced by the 20 electrical generator is desirably so regulated that the value thereof is in the order of magnitude of the value of the network voltage or corresponds thereto. That avoids undesirably high or low voltages at the generator side. Usually the network voltage is substantially constant if it involves a substantially rigid network.

#### BRIEF DESCRIPTION OF THE DRAWINGS

25 Preferred embodiments of the invention are described in greater detail hereinafter with reference to the accompanying drawings in which:

Figures 1 to 4 show various voltage and current configurations,

Figure 5 shows the harmonic component from the current configuration of Figure 4,

Figure 6 diagrammatically shows a network spur to which a wind power installation and consumer are connected,

5           Figure 7 shows an equivalent circuit diagram of an electrical line,

Figure 8 shows an equivalent circuit diagram of an electrical network with a transformer and an electrical overhead line (a) to which an electrical generator of a wind power installation is connected, as well as vector diagrams (b to e) representing various operating conditions,

10           Figure 9 shows a schematic circuit diagram of an arrangement for compensating for harmonic currents in a tap line, and

Figure 10 shows a schematic circuit diagram of an arrangement for compensating for harmonic currents in an electrical network.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

15           The occurrence of fundamental oscillation reactive powers in an electrical network has already long been known. Figures 1 to 3 show various voltage and current configurations.

20           Figure 1 shows a situation in which there is no reactive power, that is to say voltage  $U$  and current  $I$  are not phase-shifted. The current neither leads nor trails the voltage. There is therefore no fundamental oscillation reactive power.

Figure 2 shows the situation in which the current  $I$  trails the voltage  $U$  in respect of time. In this respect, inductive reactive power is required, which is the case with most electrical consumers as they - such as for example electric motors have inductors.

25           Figure 3 shows the situation in which the current  $I$  leads the voltage  $U$  in respect of time. Capacitive reactive power is required in this case.

Figure 4 shows an oscillation in the reactive power. Figure 5 shows the harmonic component from the current configuration of Figure 4.

Figure 6 shows an arrangement in which a wind power installation 2 is connected to a network spur. Consumers 6 are connected from the beginning (point A) to the end (point E) of the network spur or the electrical line 4. If the wind power installation 2 is not feeding into the network, the voltage drops increasingly 5 from the beginning (point A) to the end (point E) of the line 4; the voltage at the point E and the most closely adjacent last consumer 6 is thus lower than at the point A and the first consumer 6 which is most closely adjacent to that point A, on that electrical line 4. If now the wind power installation 2 or a larger wind park is connected at the end of the electrical line 4 at point E in Figure 6 and current is fed 10 into the electrical line 4 the connection voltage at the point E of the electrical line 4 rises in an extreme fashion. The situation which occurs is now the reverse of the case without the wind power installation 2 connected at the end of the electrical line 4.

For the situation where the electrical line is in the form of a free or 15 overhead line (no ground cable), such a line in fact essentially represents an inductor. In comparison ground cables generally represent a damped capacitor. In that respect attention is directed to the equivalent circuit diagram of a line, as shown in Figure 7.

The voltage at the feed-in point (point E in Figure 6) can be regulated 20 by means of reactive power regulation at the wind power installation. Preferably an inverter is used for that purpose.

Figure 8a shows an equivalent circuit diagram wherein the electrical generator 3 of the wind power installation 2 is connected by way of a line and a transformer to an electrical network (not shown) which is usually a fixed network. 25 Figures 8b to 8e show vector diagrams in relation to various operating conditions. In case A as shown in Figure 8b the generator 3 of the wind power installation 2 only feeds active power into the electrical network 10; it can be seen immediately that the voltage  $U_{\text{line}}$  at the feed-in point (point E) is higher than the voltage  $U_{\text{network}}$  at the point A. In case B as shown in Figure 8c a component of inductive reactive

power is fed into the network in addition to the active power and it can be seen that the voltages  $U_{\text{line}}$  and  $U_{\text{network}}$  at the end at point E and at the beginning point A are equal. The case C shown in Figure 8d illustrates in comparison that too much inductive reactive power is being fed into the network; the consequence of this is

- 5 that the voltage  $U_{\text{line}}$  at the point E becomes too low. The case D in Figure 8e shows the situation when excessive capacitive reactive power is being fed into the network; consequently the voltage  $U_{\text{line}}$  at the feed-in point/point E rises very greatly in relation to the voltage  $U_{\text{network}}$ . The latter situation absolutely has to be avoided.

10 To provide for reactive power compensation an inverter (not shown) is connected between the generator 3 and the point E as shown in Figure 8a. Now the function of such an inverter is to exactly follow a predetermined voltage value insofar as the  $\cos \varphi$  of the output current is correspondingly rapidly and dynamically regulated.

15 In addition harmonic reactive powers occur in the electrical network. More specifically, electrical consumers increasingly require a current which includes harmonics or produce harmonics in the electrical network, such as for example television units which at the input have a rectifier or industrial operations which operate regulated rectifier drives. Figure 4 shows a situation in which 20 harmonic reactive power is required. The voltage configuration U is virtually sinusoidal while the current I, besides the fundamental oscillation, also includes harmonics. It is possible to clearly see here the fifth harmonic. Figure 5 shows the required fifth harmonic as a separate component  $I_{\text{h}}$  of the current I.

Such harmonics in the current configuration (current harmonics) 25 cause in the electrical network voltage harmonics which adversely affect the quality of the voltage in the electrical network. It is therefore necessary for such harmonic reactive powers also to be compensated.

Figure 9 shows a tap line 11 which is connected with its one end (at the left in Figure 9) to an electrical network (not shown) while consumers 6 are

connected to the other end thereof (at the right in Figure 9). Such a tap line 11 can for example supply an industrial area or park or one or more villages with electric current. The current flowing to the consumers 6 is measured by means of a current transformer 12. The measurement signal from the transformer 12 is

5 passed to an evaluation circuit 14 which continuously analyses on-line which current harmonics are contained in the current on the tap line 11. That measurement results serves as a reference value which is fed as an output signal to an inverter 16 which then produces substantially at the same time the required harmonics and feeds same into the electrical line 11 upstream of the transformer

10 12. That ensures that the required harmonics reactive power is produced by the inverter 16 for compensation of the harmonic reactive power present in the electrical network, and is not taken from the electrical network.

Figure 10 diagrammatically shows the electrical network 10 whose voltage is measured by means of a voltage transformer 18. The measurement signal from the voltage transformer 18 is fed to an evaluation device 20. There is also a reference value device 22 which predetermines the desired voltage configuration. The output signal of the voltage device 20 is deducted by a subtracting device 24 from the output signal of the reference value device 22 and the difference output signal, resulting therefrom, from the subtracting device 24 is

15 fed to the inverter 10 which then substantially at the same time produces the required harmonics in order to compensate for the harmonic reactive power in the electrical network. In this arrangement therefore the network voltage is measured by means of the voltage transformer 18 and the evaluation device 20 serves to detect which harmonics are contained in the voltage configuration. More

20 specifically the harmonic currents in the electrical network 10 produce at the network impedance voltage drops corresponding to the frequency and amplitude thereof. The values which are measured and calculated in that way are predetermined for the inverter 16 as current reference values. The inverter 16

then produces, in accordance with the reference values, the current harmonics with the required frequencies, amplitudes and phase positions.

## **CLAIMS**

1. A method of reactive power regulation in an electrical network, comprising:

electrical power by an electrical generator driven by the rotor of a wind power installation and modulating the power by means of a compensation device between the generator and the network for the compensation of reactive power by adaptation of the phase and/or amplitude of the reactive power component of the delivered electrical power, regulating the compensation device so that the electrical power delivered to the consumer has a reactive power component which is adapted in respect of its phase and/or amplitude and in respect of its frequency to the consumer to compensate for the reactive power in the consumer.

2. The method according to claim 1 wherein the compensation device is so regulated that the electrical generator produces capacitive reactive power in order to compensate for the inductive reactive power in the consumer.

3. The method according to claim 1 wherein the delivered electrical power is of a frequency which corresponds to the frequency of the reactive power caused by the consumer or represents a multiple of said frequency.

4. The method according to at least one of claim 1 wherein the compensation device operates as an inverter.

5. The method according to claim 1 wherein the compensation device measures the voltage and/or current configurations in the electrical network, preferably at the feed-in point of the electrical power into the

network, and in dependence on the measurement results regulates the reactive power component in the electrical power produced by the electrical generator.

6. The method according to claim 1 wherein the voltage produced by the electrical generator is regulated substantially to a predetermined reference value with suitable adaptation of the reactive power component in the electrical power delivered to the consumer.

7. The method according to claim 6 wherein adaptation of the reactive power component is effected by suitable control of the power factor ( $\cos \varphi$ ) or the phase of the current produced by the electrical generator.

8. The method according to claim 6 in which the electrical generator is connected to an electrical network by way of a line and/or a transformer, further including the step of:

regulating the voltage produced by the electrical generator so that the value thereof is of the order of magnitude of the value of the network voltage or corresponds to the value of the network voltage.

9. An apparatus for producing electrical energy in an electrical network, comprising:

an electrical generator;  
a compensation device between the generator and the network for the compensation of reactive power by adaptation of the phase and/or amplitude of the reactive power component of the delivered electrical power; and

a regulating device which regulates the compensation device in such a way that the electrical power delivered to the consumer has a reactive power component which is adapted in respect of its phase and/or amplitude and in respect of its frequency to the consumer to compensate for the reactive power in the consumer.

10. The apparatus according to claim 9 wherein the regulating device regulates the compensation device in such a way that the electrical generator produces capacitive reactive power in order to compensate for the inductive reactive power in the consumer.

11. The apparatus according to claim 9 wherein the delivered electrical power is of a frequency which corresponds to the frequency of the reactive power caused by the consumer and represents a multiple of said frequency.

12. The apparatus according to claim 9 wherein the compensation device has an inverter.

13. The apparatus according to claim 9 wherein the regulating device has a measuring device for detecting the voltage and/or current configurations in the electrical network, preferably at the feed-in point of the electrical power into the network.

14. The apparatus according to claim 12 wherein the regulating device controls the inverter in dependence on the measurement results of the measuring device.

15. The apparatus according to claim 9 wherein the regulating device regulates the voltage produced by the electrical generator substantially to a predetermined reference value by control of the reactive power component in the electrical power delivered to the consumer.

16. The apparatus according to claim 15 wherein the regulating device effects adaptation of the reactive power component by suitable control of the power factor ( $\cos \varphi$ ) or the phase of the current delivered by the electrical generator.

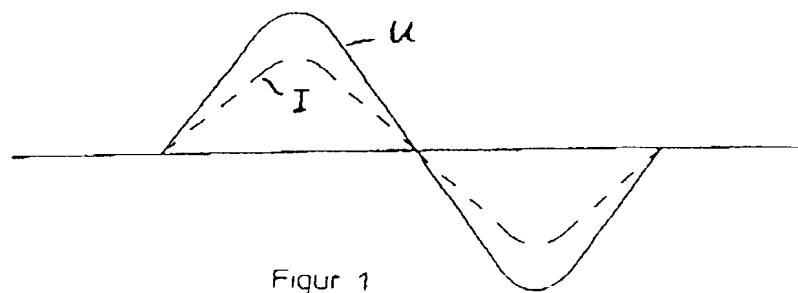
17. The apparatus according to claim 15 wherein the electrical generator is connected to an electrical network by way of a line and/or a transformer characterised in that the regulating device regulates the voltage produced by the electrical generator in such a way that the value thereof is of the order of magnitude of the value of the network voltage or corresponds to the value of the network voltage.

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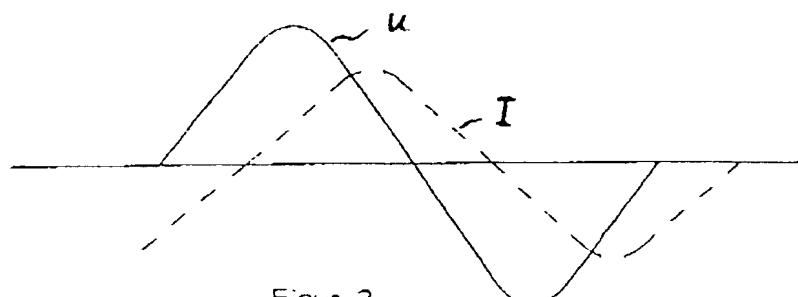
## **ABSTRACT OF THE DISCLOSURE**

The invention concerns a method of reactive power regulation in an electrical network, in which electrical power is produced by an electrical generator preferably driven by the rotor of a wind power installation and suitably modulated by means of a compensation device between the generator and the network for the compensation of reactive power, and an apparatus for producing electrical energy in an electrical network, comprising an electrical generator preferably driven by the rotor of a wind power installation and a compensation device between the generator and the network for the compensation of reactive power. The particularity of the invention is that the compensation device is so regulated that the electrical power delivered to the consumer has a reactive power component which is adapted in respect of its phase, amplitude and/or frequency to the consumer in such a way as to compensate for the reactive power in the consumer.

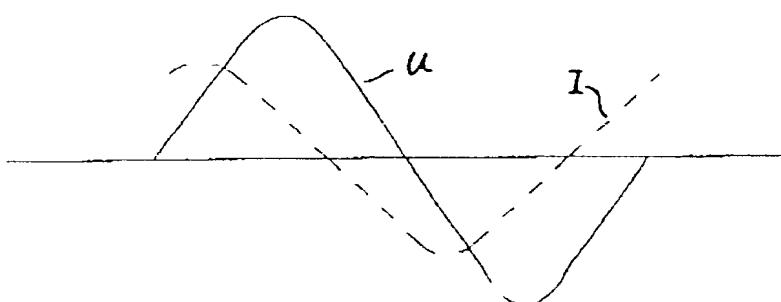
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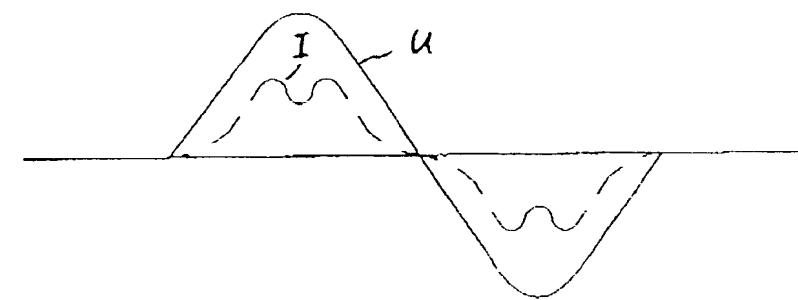
Figur 1



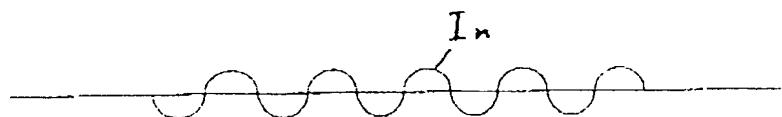
Figur 2



Figur 3

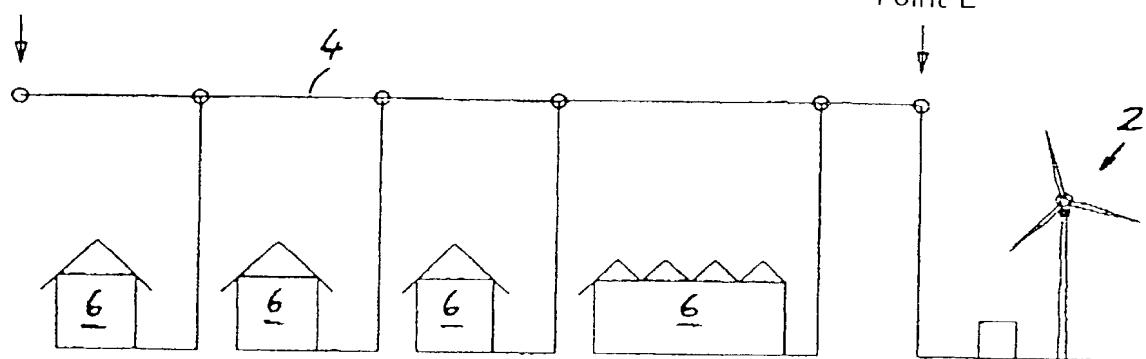


Figur 4

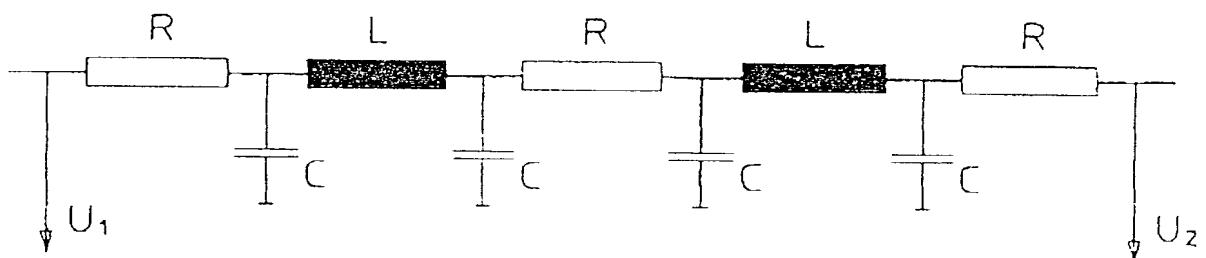


Figur 5

Point A



Figur 6



Figur 7

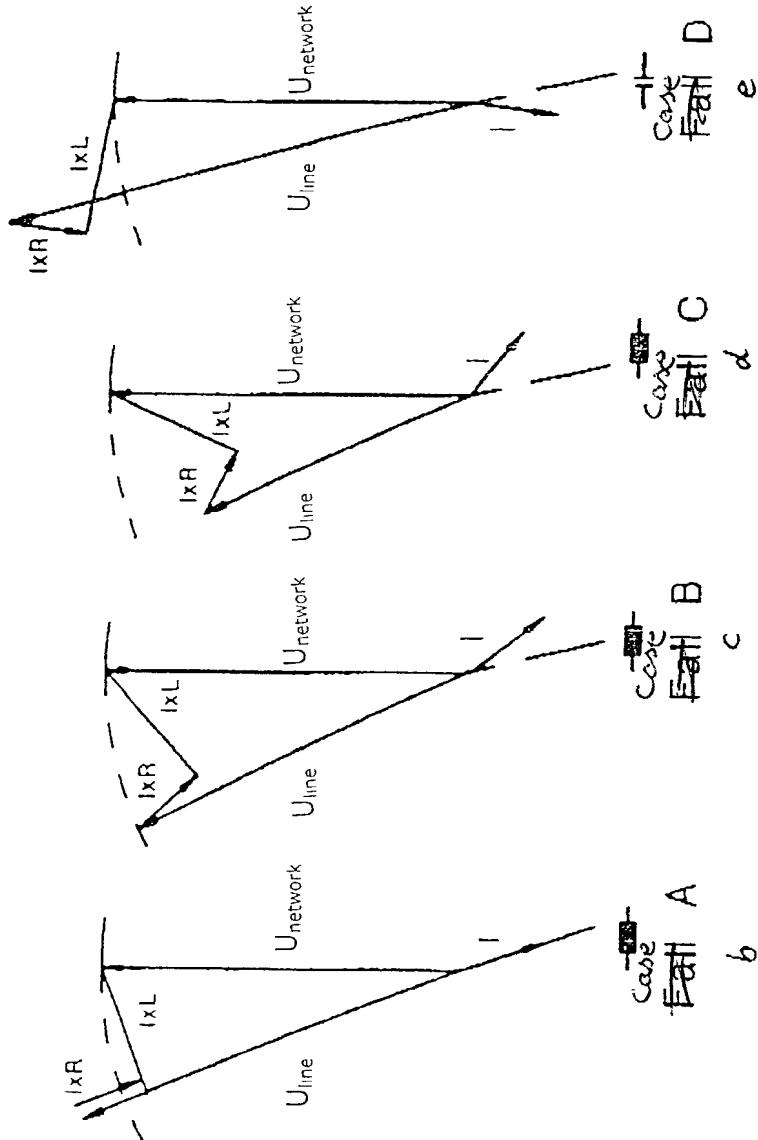
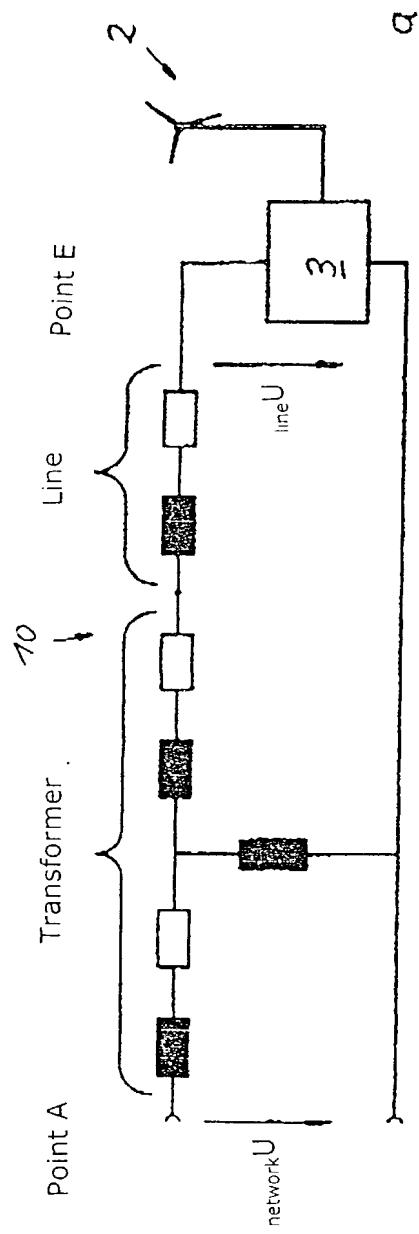
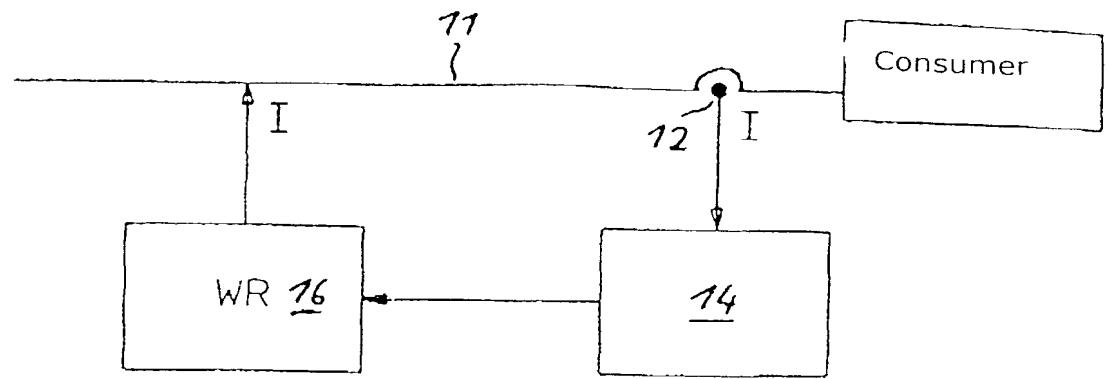
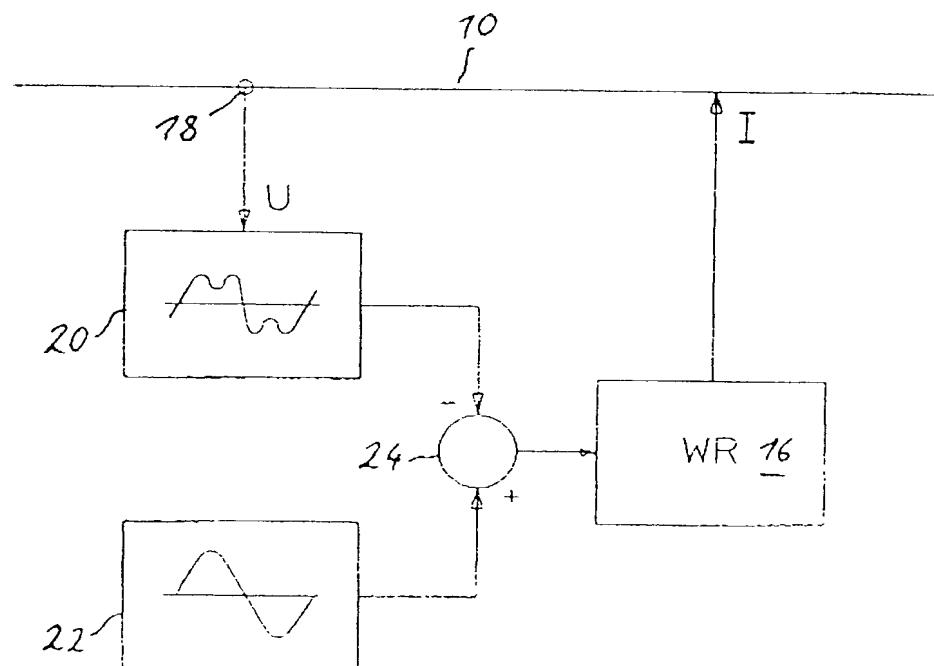


Figure 8



Figur 9



Figur 10

Aloys Wobben, Argestrasse 19, 26607 Aurich

Method of reactive power regulation and apparatus for producing electrical  
5 energy in an electrical network

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The invention concerns a method of reactive power regulation in an electrical network, in which electrical power is produced by an electrical generator preferably driven by the rotor of a wind power installation and  
10 suitably modulated by means of a compensation device between the generator and the network for the compensation of reactive power. The invention further concerns an apparatus for producing electrical energy in an electrical network, comprising an electrical generator preferably driven by the rotor of a wind power installation and a compensation device  
15 between the generator and the network for the compensation of reactive power.

Many consumers connected to the electrical network require inductive reactive power. Compensation of such an inductive reactive power component is effected by using capacitors which are also referred to as  
20 phase-shifting capacitors whose capacitive reactance is approximately as high as the inductive reactance. Complete compensation of the inductive reactive power by means of phase-shifting capacitors is however not possible in practice precisely when high power fluctuations are involved. A further disadvantage is that the phase-shifting capacitors required, which  
25 are frequently combined together to form what is referred to as capacitor batteries and which moreover take up a great deal of space have a negative effect on the stability of the electrical network.

The object of the present invention is to avoid the above-mentioned disadvantages of the state of the art and to compensate for the reactive power in an electrical network in a simple fashion.  
30

In a method and an apparatus of the kind set forth in the opening part of this specification, that object is attained in that the compensation device is so regulated that the electrical power delivered to the consumer

has a reactive power component which is adapted in respect of its phase, amplitude and/or frequency to the consumer in such a way as to compensate for the reactive power in the consumer.

In accordance with the invention, by means of the compensation device, a reactive power is 'produced', which is in a position to compensate for the reactive power in the consumer. For example, by means of the compensation device according to the invention, it is possible to produce a capacitive reactive power component which is adapted to the inductive reactive power component required by the consumer, in such a way that it substantially completely compensates for the inductive reactive power component in the consumer. The advantage of the invention is thus essentially that there is provided a regulating system which rapidly reacts in particular to frequently occurring high power fluctuations, so that complete reactive power compensation is substantially maintained.

Accordingly, inductive or capacitive reactive power can be fed selectively into the electrical network, which in accordance with the invention is implemented by regulation of the compensation device.

In this respect, by means of the regulation in accordance with the invention, it is preferably also possible for the electrical power produced to be of a frequency which corresponds to the frequency of the consumer or also represents a multiple of the consumer frequency. In the former case accordingly reactive power can be supplied at the frequency of the consumer or the network frequency of the electrical network. In the latter case for example as desired harmonic reactive power can be fed into the electrical network. For example the fifth harmonic can be fed into the network, at a frequency of 250 Hz, as a capacitive harmonic. That then compensates for the harmonic reactive power of electrical consumers which are connected to the electrical network such as for example televisions, energy-saving lamps and so forth.

Desirably the compensation device has an inverter with which phase, amplitude and/or frequency of the voltage and/or current characteristics can be particularly easily adjusted or regulated in order to produce a

reactive power component which is suitable for appropriately compensating for the reactive power in the consumer.

Preferably the compensation device has a measuring device for detecting the voltage and/or current variations in the electrical network, 5 preferably at the feed-in point. In a development of the embodiment in which the compensation device includes an inverter the compensation device controls the inverter in dependence on the measurement results of the measuring device.

The voltage produced by the electrical generator is preferably 10 regulated substantially to a predetermined reference value with suitable adaptation of the reactive power component in the electrical power delivered to the consumer. In that situation adaptation of the reactive power component can take place by suitable control of the power factor ( $\cos \phi$ ) or the phase of the current produced by the electrical generator. If 15 the electrical generator is connected to an electrical network by way of a line and/or a transformer then the voltage produced by the electrical generator is desirably so regulated that the value thereof is in the order of magnitude of the value of the network voltage or corresponds thereto. That avoids undesirably high or low voltages at the generator side. Usually the 20 network voltage is substantially constant if it involves a substantially rigid network.

Preferred embodiments of the invention are described in greater detail hereinafter with reference to the accompanying drawings in which:

Figures 1 to 4 show various voltage and current configurations, 25 Figure 5 shows the harmonic component from the current configuration of Figure 4,

Figure 6 diagrammatically shows a network spur to which a wind power installation and consumer are connected,

Figure 7 shows an equivalent circuit diagram of an electrical line, 30 Figure 8 shows an equivalent circuit diagram of an electrical network with a transformer and an electrical overhead line (a) to which an electrical generator of a wind power installation is connected, as well as vector diagrams (b to e) representing various operating conditions,

Figure 9 shows a schematic circuit diagram of an arrangement for compensating for harmonic currents in a tap line, and

Figure 10 shows a schematic circuit diagram of an arrangement for compensating for harmonic currents in an electrical network.

5 The occurrence of fundamental oscillation reactive powers in an electrical network has already long been known. Figures 1 to 3 show various voltage and current configurations.

10 Figure 1 shows a situation in which there is no reactive power, that is to say voltage  $U$  and current  $I$  are not phase-shifted. The current neither leads nor trails the voltage. There is therefore no fundamental oscillation reactive power.

15 Figure 2 shows the situation in which the current  $I$  trails the voltage  $U$  in respect of time. In this respect, inductive reactive power is required, which is the case with most electrical consumers as they - such as for example electric motors - have inductors.

Figure 3 shows the situation in which the current  $I$  leads the voltage  $U$  in respect of time. Capacitive reactive power is required in this case.

20 Figure 6 shows an arrangement in which a wind power installation 2 is connected to a network spur. Consumers 6 are connected from the beginning (point A) to the end (point E) of the network spur or the electrical line 4. If the wind power installation 2 is not feeding into the network, the voltage drops increasingly from the beginning (point A) to the end (point E) of the line 4; the voltage at the point E and the most closely adjacent last consumer 6 is thus lower than at the point A and the first consumer 6 which is most closely adjacent to that point A, on that electrical line 4. If now the wind power installation 2 or a larger wind park is connected at the end of the electrical line 4 at point E in Figure 6 and current is fed into the electrical line 4 the connection voltage at the point E of the electrical line 4 rises in an extreme fashion. The situation which occurs is now the reverse of the case without the wind power installation 2 connected at the end of the electrical line 4.

For the situation where the electrical line is in the form of a free or overhead line (no ground cable), such a line in fact essentially represents

an inductor. In comparison ground cables generally represent a damped capacitor. In that respect attention is directed to the equivalent circuit diagram of a line, as shown in Figure 7.

The voltage at the feed-in point (point E in Figure 6) can be  
 5 regulated by means of reactive power regulation at the wind power  
 installation. Preferably an inverter is used for that purpose.

Figure 8a shows an equivalent circuit diagram wherein the electrical generator 3 of the wind power installation 2 is connected by way of a line and a transformer to an electrical network (not shown) which is usually a fixed network. Figures 8b to 8e show vector diagrams in relation to various operating conditions. In case A as shown in Figure 8b the generator 3 of the wind power installation 2 only feeds active power into the electrical network 10; it can be seen immediately that the voltage  $U_{\text{line}}$  at the feed-in point (point E) is higher than the voltage  $U_{\text{network}}$  at the point A. In case B as shown in Figure 8c a component of inductive reactive power is fed into the network in addition to the active power and it can be seen that the voltages  $U_{\text{line}}$  and  $U_{\text{network}}$  at the end at point E and at the beginning point A are equal. The case C shown in Figure 8d illustrates in comparison that too much inductive reactive power is being fed into the network; the consequence of this is that the voltage  $U_{\text{line}}$  at the point E becomes too low. The case D in Figure 8e shows the situation when excessive capacitive reactive power is being fed into the network; consequently the voltage  $U_{\text{line}}$  at the feed-in point/point E rises very greatly in relation to the voltage  $U_{\text{network}}$ . The latter situation absolutely has to be avoided.

To provide for reactive power compensation an inverter (not shown) is connected between the generator 3 and the point E as shown in Figure 8a. Now the function of such an inverter is to exactly follow a predetermined voltage value insofar as the  $\cos \varphi$  of the output current is correspondingly rapidly and dynamically regulated.

30 In addition harmonic reactive powers occur in the electrical network.  
More specifically, electrical consumers increasingly require a current which  
includes harmonics or produce harmonics in the electrical network, such as  
for example television units which at the input have a rectifier or industrial

operations which operate regulated rectifier drives. Figure 4 shows a situation in which harmonic reactive power is required. The voltage configuration U is virtually sinusoidal while the current I, besides the fundamental oscillation, also includes harmonics. It is possible to clearly  
5 see here the fifth harmonic. Figure 5 shows the required fifth harmonic as a separate component  $I_5$  of the current I.

Such harmonics in the current configuration (current harmonics) cause in the electrical network voltage harmonics which adversely affect  
10 the quality of the voltage in the electrical network. It is therefore necessary for such harmonic reactive powers also to be compensated.

Figure 9 shows a tap line 11 which is connected with its one end (at the left in Figure 9) to an electrical network (not shown) while consumers 6 are connected to the other end thereof (at the right in Figure 9). Such a tap line 11 can for example supply an industrial area or park or one or more  
15 villages with electric current. The current flowing to the consumers 6 is measured by means of a current transformer 12. The measurement signal from the transformer 12 is passed to an evaluation circuit 14 which continuously analyses on-line which current harmonics are contained in the current on the tap line 11. That measurement results serves as a reference  
20 value which is fed as an output signal to an inverter 16 which then produces substantially at the same time the required harmonics and feeds same into the electrical line 11 upstream of the transformer 12. That ensures that the required harmonics reactive power is produced by the  
25 inverter 16 for compensation of the harmonic reactive power present in the electrical network, and is not taken from the electrical network.

Figure 10 diagrammatically shows the electrical network 10 whose voltage is measured by means of a voltage transformer 18. The measurement signal from the voltage transformer 18 is fed to an evaluation device 20. There is also a reference value device 22 which  
30 predetermines the desired voltage configuration. The output signal of the voltage device 20 is deducted by a subtracting device 24 from the output signal of the reference value device 22 and the difference output signal, resulting therefrom, from the subtracting device 24 is fed to the inverter 10

7

which then substantially at the same time produces the required harmonics in order to compensate for the harmonic reactive power in the electrical network. In this arrangement therefore the network voltage is measured by means of the voltage transformer 18 and the evaluation device 20 serves 5 to detect which harmonics are contained in the voltage configuration. More specifically the harmonic currents in the electrical network 10 produce at the network impedance voltage drops corresponding to the frequency and amplitude thereof. The values which are measured and calculated in that way are predetermined for the inverter 16 as current reference values. The 10 inverter 16 then produces, in accordance with the reference values, the current harmonics with the required frequencies, amplitudes and phase positions.

New claims 1 to 17

1. A method of reactive power regulation in an electrical network (10), in which electrical power is produced by an electrical generator (3) preferably driven by the rotor of a wind power installation (2) and suitably modulated by means of a compensation device (16) between the generator (3) and the network (10) for the compensation of reactive power by adaptation of the phase and/or amplitude of the reactive power component of the delivered electrical power, characterised in that the compensation device (16) is so regulated that the electrical power delivered to the consumer (6) has a reactive power component which is adapted in respect of its phase and/or amplitude and in respect of its frequency to the consumer (6) to compensate for the reactive power in the consumer (6).

2. A method according to claim 1 characterised in that the compensation device (16) is so regulated that the electrical generator (3) produces capacitive reactive power in order to compensate for the inductive reactive power in the consumer (6).

3. A method according to claim 1 or claim 2 characterised in that the delivered electrical power is of a frequency which corresponds to the frequency of the reactive power caused by the consumer (6) or represents a multiple of said frequency.

4. A method according to at least one of claims 1 to 3 characterised in that the compensation device operates as an inverter (16).

5. A method according to at least one of claims 1 to 4 characterised in that the compensation device (16) measures the voltage and/or current configurations in the electrical network (10), preferably at the feed-in point (E) of the electrical power into the network, and in dependence on the

measurement results regulates the reactive power component in the electrical power produced by the electrical generator (3).

6. A method according to at least one of claims 1 to 5 characterised in that the voltage produced by the electrical generator (3) is regulated substantially to a predetermined reference value with suitable adaptation of the reactive power component in the electrical power delivered to the consumer (6).

7. A method according to claim 6 characterised in that adaptation of the reactive power component is effected by suitable control of the power factor ( $\cos \varphi$ ) or the phase of the current produced by the electrical generator (3).

8. A method according to claim 6 or claim 7 in which the electrical generator (3) is connected to an electrical network by way of a line and/or a transformer, characterised in that the voltage produced by the electrical generator (3) is so regulated that the value thereof is of the order of magnitude of the value of the network voltage or corresponds to the value of the network voltage.

9. Apparatus for producing electrical energy in an electrical network (10), comprising an electrical generator (3) preferably driven by the rotor of a wind power installation (2) and a compensation device (16) between the generator (3) and the network (10) for the compensation of reactive power by adaptation of the phase and/or amplitude of the reactive power component of the delivered electrical power, characterised by a regulating device (14; 20, 22, 24) which regulates the compensation device (16) in such a way that the electrical power delivered to the consumer (6) has a reactive power component which is adapted in respect of its phase and/or amplitude and in respect of its frequency to the consumer (6) to compensate for the reactive power in the consumer (6).

10. Apparatus according to claim 9 characterised in that the regulating device (14; 20, 22, 24) regulates the compensation device (16) in such a way that the electrical generator (3) produces capacitive reactive power in order to compensate for the inductive reactive power in the consumer (6).

11. Apparatus according to claim 9 or claim 10 characterised in that the delivered electrical power is of a frequency which corresponds to the frequency of the reactive power caused by the consumer (6) and represents a multiple of said frequency.

12. Apparatus according to at least one of claims 9 to 11 characterised in that the compensation device (16) has an inverter (16).

13. Apparatus according to at least one of claims 9 to 12 characterised in that the regulating device (14; 20, 22, 24) has a measuring device (12; 18) for detecting the voltage and/or current configurations in the electrical network (10), preferably at the feed-in point (E) of the electrical power into the network.

14. Apparatus according to claims 12 and 13 characterised in that the regulating device (14; 20, 22, 24) controls the inverter (16) in dependence on the measurement results of the measuring device (12; 18).

15. Apparatus according to at least one of claims 9 to 14 characterised in that the regulating device (14; 20, 22, 24) regulates the voltage produced by the electrical generator (3) substantially to a predetermined reference value by control of the reactive power component in the electrical power delivered to the consumer (6).

16. Apparatus according to claim 15 characterised in that the regulating device (14; 20, 22, 24) effects adaptation of the reactive power

component by suitable control of the power factor ( $\cos \varphi$ ) or the phase of the current delivered by the electrical generator (3).

17. Apparatus according to claim 15 or claim 16 in which the electrical generator (3) is connected to an electrical network by way of a line and/or a transformer characterised in that the regulating device regulates the voltage produced by the electrical generator (3) in such a way that the value thereof is of the order of magnitude of the value of the network voltage or corresponds to the value of the network voltage.

Abstract

The invention concerns a method of reactive power regulation in an electrical network, in which electrical power is produced by an electrical generator preferably driven by the rotor of a wind power installation and suitably modulated by means of a compensation device between the generator and the network for the compensation of reactive power, and an apparatus for producing electrical energy in an electrical network, comprising an electrical generator preferably driven by the rotor of a wind power installation and a compensation device between the generator and the network for the compensation of reactive power. The particularity of the invention is that the compensation device is so regulated that the electrical power delivered to the consumer has a reactive power component which is adapted in respect of its phase, amplitude and/or frequency to the consumer in such a way as to compensate for the reactive power in the consumer.

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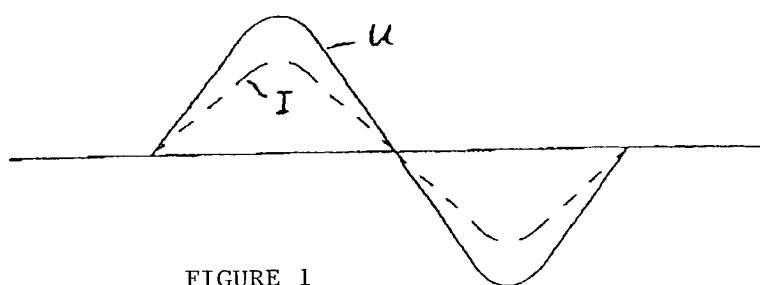


FIGURE 1

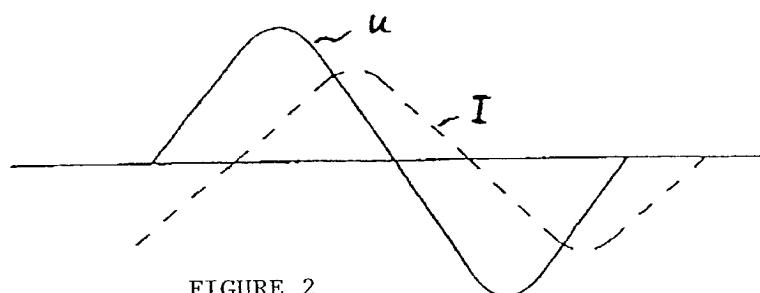


FIGURE 2

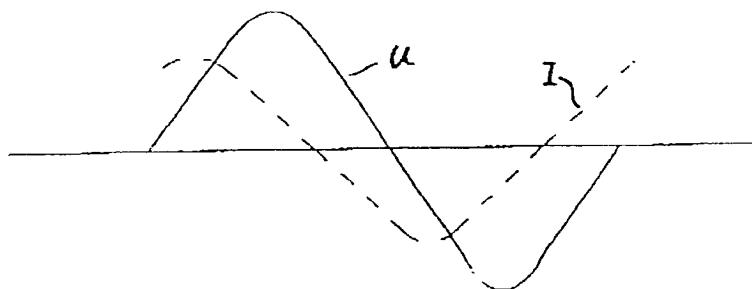


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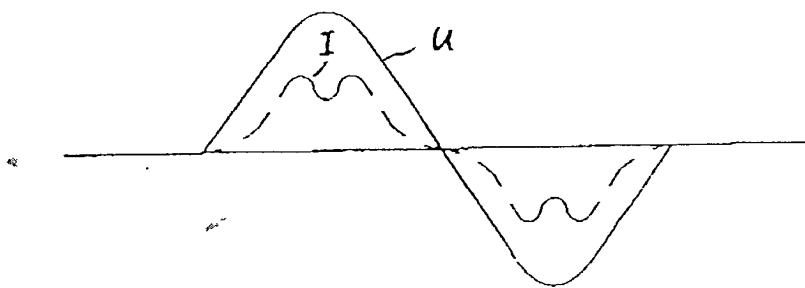


FIGURE 4

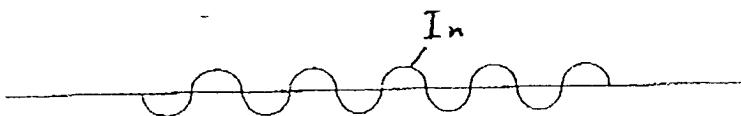


FIGURE 5

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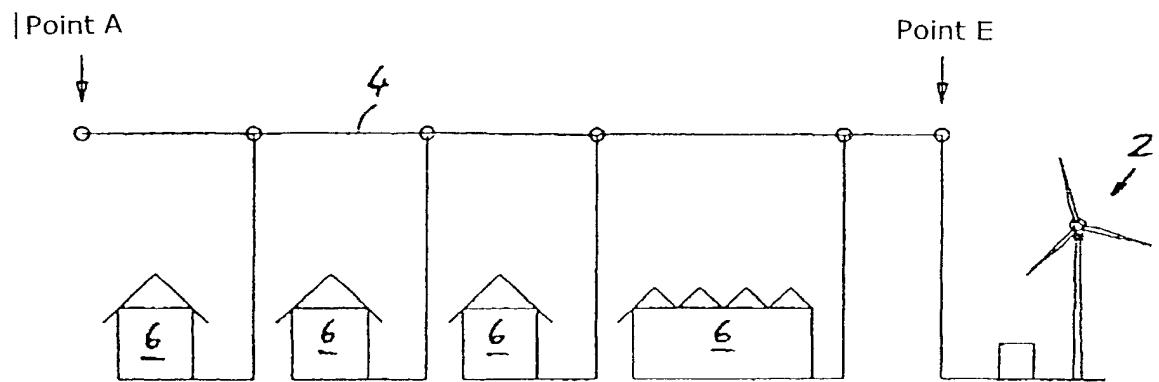


FIGURE 6

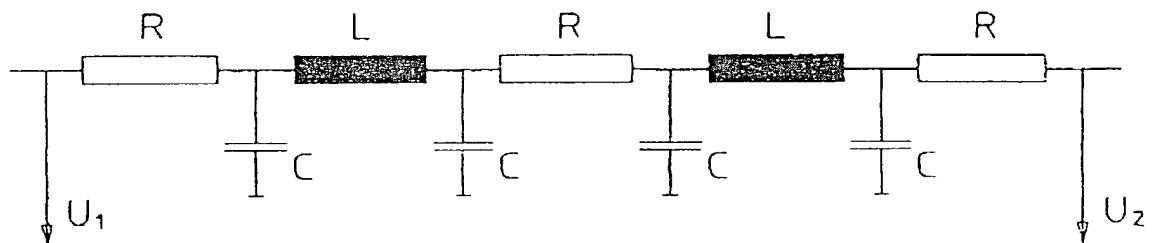


FIGURE 7

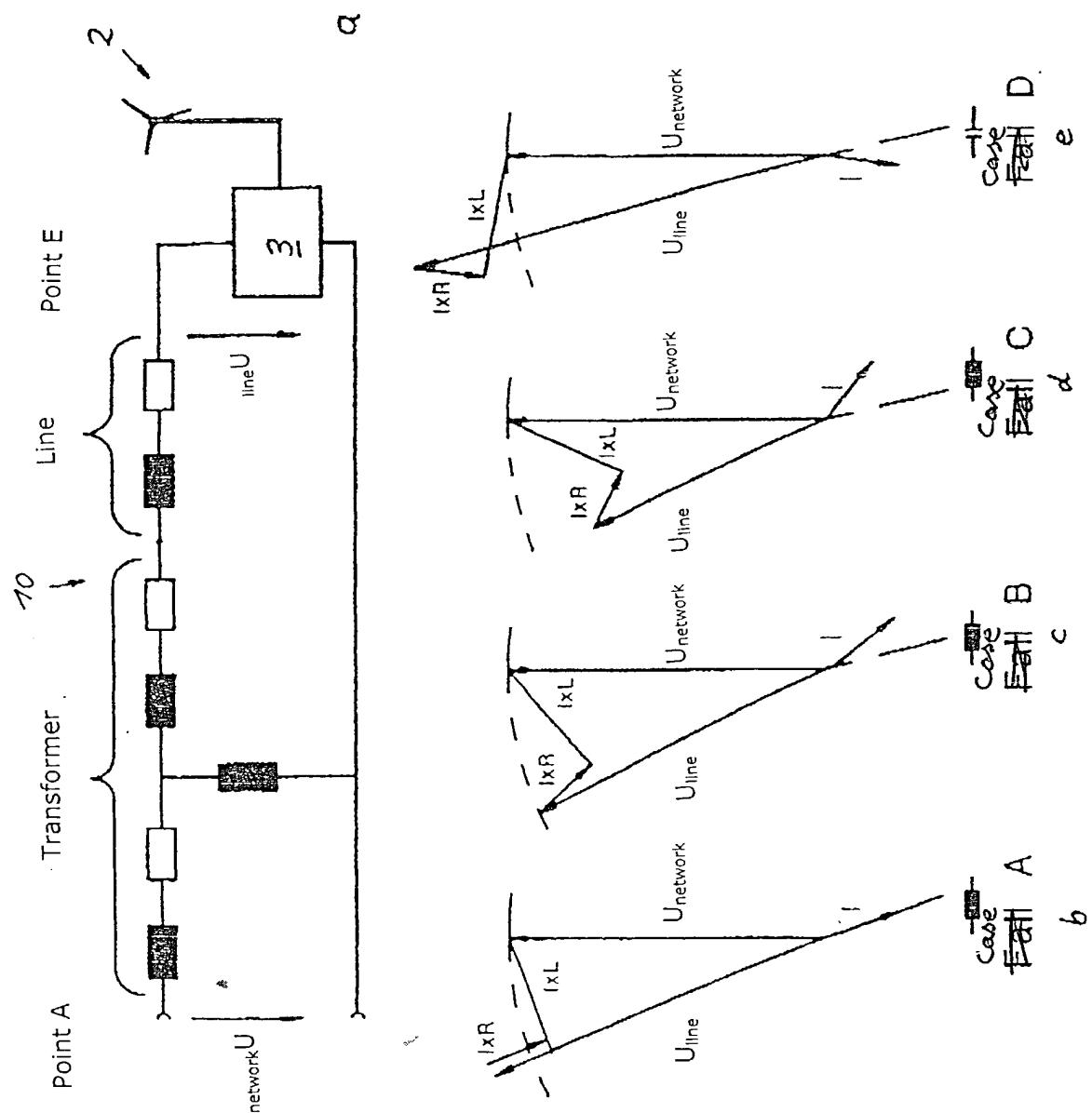


FIGURE 8

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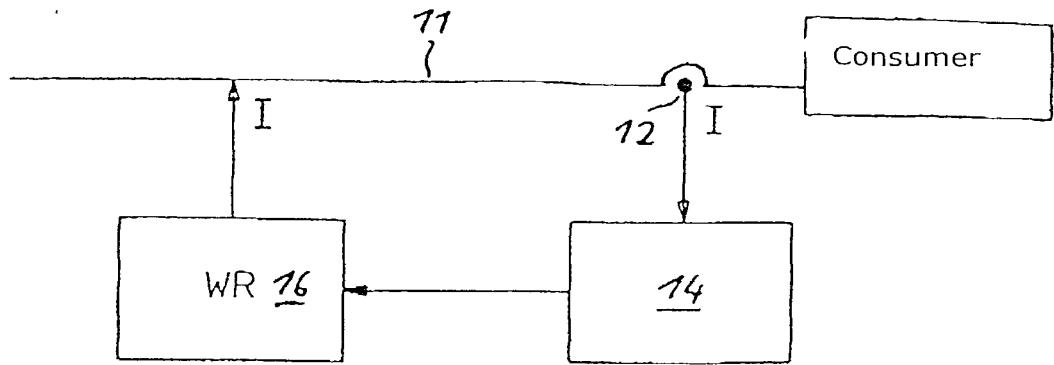


FIGURE 9

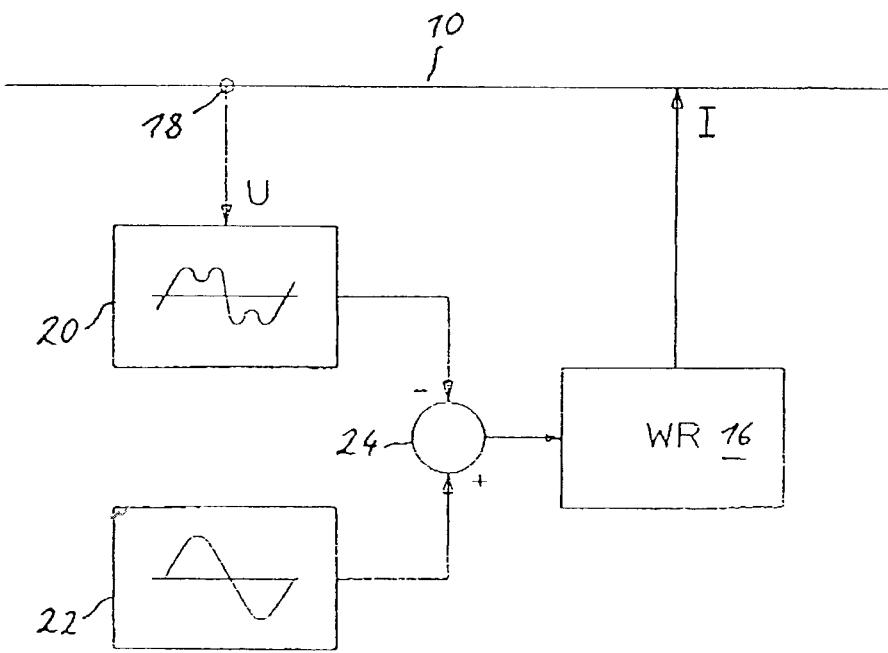


FIGURE 10

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**DECLARATION FOR  
UTILITY OR DESIGN  
PATENT APPLICATION  
(37 CFR 1.63)**

Attorney Docket No. **970054.413USPC**First Named Inventor **Aloys Wobben****COMPLETE IF KNOWN**Application Number **10/088,011**

Filing Date

Group Art Unit **Not yet known**Examiner's Name **Not yet known** Declaration Submitted with Initial Filing Declaration Submitted after Initial Filing**As the below named inventor(s), I/we hereby declare that:**

My residence, post office address, and citizenship are as stated below next to my name.

I/we believe that I/we am/are the original and first inventor(s) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

**METHOD OF REACTIVE POWER REGULATION AND APPARATUS FOR PRODUCING ELECTRICAL ENERGY IN AN ELECTRICAL NETWORK***(Title of Invention)*

the specification of which was filed on (MM/DD/YYYY)

**07 September 2000**the specification of which is attached hereto  

as United States Application Number or PCT International Application Number

**PCT/EP00/08745**Express Mail No.  and was amended on (MM/DD/YYYY) *(if applicable)*  

I/we have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment specifically referred to above.

In addition, I/we acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me/us to be material to patentability as defined in 37 CFR 1.56, including material information which became available between the filing date of the prior application and the National or PCT International filing date of the continuation-in-part application, if applicable.

I/we hereby claim foreign priority benefits under 35 U.S.C. 119(a)-(d) or (f), or 365(b) of any foreign application(s) for patent or inventor's certificate, or 365(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or of any PCT international application having a filing date before that of the application on which priority is claimed.

| Prior Foreign Application Number(s) | Country | Foreign Filing Date (MM/DD/YYYY) | Priority Claimed | Certified Copy Attached? YES | NO |
|-------------------------------------|---------|----------------------------------|------------------|------------------------------|----|
| ✓ 19943847.1                        | DE      | 13 September 1999                | Y                |                              | X  |
| ✓ 10020635.2                        | DE      | 27 April 2000                    | Y                |                              | X  |
| PCT/EP00/08745                      | WO      | 07 September 2000                | Y                |                              | X  |

Additional foreign application numbers are not listed on a supplemental priority data sheet PTO/SB/02B attached hereto.

I/we hereby claim the benefit under 35 U.S.C. 119(e) of any United States provisional application(s) listed below.

| Application No. | Filing Date (MM/DD/YYYY) | Application No. | Filing Date (MM/DD/YY) |
|-----------------|--------------------------|-----------------|------------------------|
|                 |                          |                 |                        |

Additional provisional application numbers are not listed on a supplemental priority data sheet PTO/SB/02B attached hereto.

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| <u>Aloys</u>                           |                       |                     | <u>WOBBEN</u>          |         |               |             |           |
| Inventor's Signature                   | <i>Wobben</i>         |                     |                        | Date    | 21 March 2002 |             |           |
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| Inventor's Signature                   |  |       |                        | Date    |  |             |  |
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| Additional Inventor:                   |  |       |                        |         |  |             |  |
| Given Name (first and middle [if any]) |  |       | Family Name or Surname |         |  |             |  |
|                                        |  |       |                        |         |  |             |  |
| Inventor's Signature                   |  |       |                        | Date    |  |             |  |
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|-------------------------------------------------------------------------|------------------------|----------------|
| <b>ELECTION AND POWER OF<br/>ATTORNEY OR<br/>AUTHORIZATION OF AGENT</b> | Application Number     | 10/088,011     |
|                                                                         | Filing Date            |                |
|                                                                         | First Named Inventor   | Aloys Wobben   |
|                                                                         | Group Art Unit         | Not yet known  |
|                                                                         | Examiner Name          | Not yet known  |
|                                                                         | Attorney Docket Number | 970054.413USPC |

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I am the:

Applicant/Inventor.

Assignee of record of the entire interest. See 37 CFR 3.71.

Statement under 37 CFR 3.73(b) is enclosed. (Form PTO/SB/96).

As assignee of record of the entire interest hereby elect, under 37 C.F.R. § 3.71, to prosecute the application to the exclusion of the inventor

**SIGNATURE of Applicant or Assignee of Record**

|           |               |
|-----------|---------------|
| Name      | Aloys Wobben  |
| Signature |               |
| Date      | 21 March 2002 |

NOTE: Signatures of all the inventors or assignees of record of the entire interest or their representative(s) are required.  
Submit multiple forms if more than one signature is required, see below\*.

\*Total of 2 forms are submitted.

Burden Hour Statement: This form is estimated to take 3 minutes to complete. Time will vary depending upon the needs of the individual case. Any comments on the amount of time you are required to complete this form should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, Washington, DC 20231. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Assistant Commissioner for Patents, Washington, DC 20231